AAMRL-TR-90-044

AD-A230 454

ENHANCING THE TOLERANCE TO +GZ ACCELERATION BY OPTIMIZING THE USE OF ISOMETRIC CONTRACTIONS IN COMBINATION WITH STRAINING MANEUVERS

CAROLE A. WILLIAMS, PH.D.
DEPARTMENT OF PHYSIOLOGY
COLLEGE OF MEDICINE
EAST TENNESSEE STATE UNIVERSITY

J. MARTIN
J. MOFFATT
J.E. DOUGLAS, M.D.
A.R. LIND*
D. PHIL
D. SCI

*DEPARTMENT OF PHYSIOLOGY
ST. LOUIS UNIVERSITY SCHOOL OF MEDICINE

AUGUST 1990

FINAL REPORT

Approved for public release; distribution is unlimited

HARRY G. ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
HUMAN SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-6573

NOTICES

TECHNICAL REVIEW AND APPROVAL

AAMRL-TR-90-044

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

James W. Brinkley

JAMES W. BRINKLEY, SES
Director
Biodynamics and Bioengineering Division
Harry G. Armstrong Aerospace Medical Research Laboratory

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AAMRL-TR-90-044	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION EAST TENNESSEE STATE UNIVERSITY 6b. OFFICE SYMBOL *(If applicable)*	7a. NAME OF MONITORING ORGANIZATION HARRY G. ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
6c. ADDRESS *(City, State, and ZIP Code)* DEPT OF PHYSIOLOGY, COLLEGE OF MEDICINE P.O. BOX 19780A, JOHNSON CITY, TN 37614-0002	7b. ADDRESS *(City, State, and ZIP Code)* WRIGHT-PATTERSON AFB, OH 45433-6573
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL *(If applicable)*	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-85-C-0530
8c. ADDRESS *(City, State, and ZIP Code)*	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61101F PROJECT NO. 7231 TASK NO 25 WORK UNIT ACCESSION NO. 01

11. TITLE *(Include Security Classification)*

(U) Enhancing the Tolerance to +Gz Acceleration by Optimizing the Use of Isometric Contractions in Combination with Straining Maneuvers

12. PERSONAL AUTHOR(S)

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Year, Month, Day)*	15. PAGE COUNT
Final	FROM Oct 86 TO Sep 87	90 Aug	42

16. SUPPLEMENTARY NOTATION

Carole A. Williams, J. Martin, J. Moffatt, J.E. Douglas, A.R. Lind

17. COSATI CODES			18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
FIELD	GROUP	SUB-GROUP	
20	14		L-1 Esophageal Pressure
06	04		Intrathoracic Pressure

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Experiments were performed on 9 male subjects who exerted L-1 straining maneuvers in a pilot chair apparatus with a seatback at 30° and a spine-to-thigh angle of 110°. The L-1 maneuvers were performed with or without simultaneous application of isometric contractions. Contractions were exerted at high levels of force in either a sustained fashion or in an intermittent fashion, in 15 sec periods, until fatigue occurred. Isometric contractions were exerted by either the forearm flexors (handgrip), quadriceps, or jaw muscles at tensions of 70% MVC (handgrip, quadriceps) or 100% MVC (jaw). During the experiments, changes in arterial pressure, heart rate and electromyographic activity, from the intercostals and the contracting muscle group, were recorded. During the L-1 maneuver alone, mean blood pressure (MBP) increased to 205 ± 1.5 mmHg initially at the onset of the maneuver, but then fell by 50 mmHg, to 155 ± 2.5 mmHg during the first 5 sec of the procedure. The MBP recovered to 170 ± 3.5 mmHg and remained at this level during the last 5 sec of the procedure. When isometric contractions were simultaneously applied, initial MBP were essentially the same as

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Tamara Chelette	22b. TELEPHONE *(Include Area Code)* 513-255-5742 22c. OFFICE SYMBOL AAMRL/BBS

Block 19 continued:

with the L-1 maneuver alone, but there was significantly higher MBP maintained throughout the remainder of the L-1 procedure with the isometric contractions, such that MBP averaged almost 30 mmHg higher during the last 5 sec of the procedure. Both the quadriceps and handgrip contractions generated MBP at 203 mmHg by the end of the straining maneuver, while jaw contractions were slightly less effective, elevating the MBP to only 189 mmHg by the end of the procedure. The EMG of both the handgrip and quadriceps muscles increased during the high intensity contractions, signifying muscular fatigue, while the EMG from the jaw muscles demonstrated a slight decrease. We conclude that simultaneous application of high intensity isometric exercise, which can induce fatigue of the target muscle group rapidly, is an effective means of elevating arterial pressure significantly above thepressures generated by the L-1 maneuver alone, and may afford the pilot in high performance aircraft an increase in almost 1 Gz more tolerance.

PREFACE

The experiments described in this report were carried out to determine whether simultaneous application of the L-1 maneuver with isometric contractions at relatively high tensions would produce either a higher arterial pressure or a more sustained elevated pressure than that produced by the L-1 maneuver alone. These data would have potential application for the procedures recommended to pilots of high performance aircraft to withstand high +Gz forces.

The research was performed at the Quillen-Dishner College of Medicine, East Tennessee State University in the Department of Physiology under Contract Project F33615-85-C-0530, Systems Research Laboratories, Inc. and the Harry G. Armstrong Aerospace Medical Research Laboratory, and funded under the In-house Laboratory Independent Research (ILIR) Program (87-12) under Program Element 61101F.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

ABSTRACT

Experiments were performed on 9 male subjects who exerted L-1 straining maneuvers in a pilot-chair apparatus with a seatback at 30° and a spine-to-thigh angle of 110°. The L-1 maneuvers were performed with or without simultaneous application of isometric contractions. Contractions were exerted at high levels of force in either a sustained fashion or in an intermittent fashion, in 15 sec periods, until fatigue occurred. Isometric contractions were exerted by either the forearm flexors (handgrip), quadriceps, or jaw muscles at tensions of 70% MVC (handgrip, quadriceps) or 100% MVC (jaw). During the experiments, changes in arterial pressure, heart rate and electromyographic activity, from the intercostals and the contracting muscle group, were recorded. During the L-1 maneuver alone, mean blood pressure (MBP) increased to 205 $\pm$ 1.5 mmHg initially at the onset of the maneuver, but then fell by 50 mmHg, to 155 $\pm$ 2.5 mmHg during the first 5 sec of the procedure. The MBP recovered to 170 $\pm$ 3.5 mmHg and remained at this level during the last 5 sec of the procedure. When isometric contractions were simultaneously applied, initial MBP were essentially the same as with the L-1 maneuver alone, but there was significantly higher MBP maintained throughout the remainder of the L-1 procedure with the isometric contractions, such that MBP averaged almost 30 mmHg higher during the last 5 sec of the procedure. Both the quadriceps and handgrip contractions generated MBP at 203 mmHg by the end of the straining maneuver, while jaw contractions were slightly less effective, elevating the MBP to only 189 mmHg by the end of the procedure. The EMG of both the handgrip and quadriceps muscles increased during the

high intensity contractions, signifying muscular fatigue, while the EMG from the jaw muscles demonstrated a slight decrease. We conclude that simultaneous application of high intensity isometric exercise, which can induce fatigue of the target muscle group rapidly, is an effective means of elevating arterial pressure significantly above the pressures generated by the L-1 maneuver alone, and may afford the pilot in high performance aircraft an increase in almost 1 Gz more tolerance.

METHODS

1. Subjects:

Ten male subjects volunteered for this study. All were recruited from the graduate and medical student population of the College of Medicine. All subjects were informed of the purposes and procedures of the experiments according to the regulations of HHS and the Institutional Review Board of East Tennessee State University. Each subject signed an informed consent form. There were no untoward effects resulting from any of the procedures carried out in the study.

A summary of anthropometric data about the subjects is given in Table 1 (see p. 32). One subject decided to withdraw from the study after the training period. Two of the subjects (B and C) participated in a previous study (see Williams et al - AAMRL-TR-87-049).

2. Training

Subjects trained for 3 days each week for 3-4 weeks. On each day of training, subjects exerted 2 maximum voluntary contractions for each muscle group: handgrip, quadriceps and jaw. For the handgrip, a dynamometer (Clark, Hellon and Lind, 1963) was positioned next to the arm of the chair apparatus so that subjects remained in the same position in the chair as when exerting an L-1 maneuver alone. For quadriceps contractions, a steel bar containing 2 sets of strain gauges (Micromeasurements) was positioned into the back plate of the chair and a strap was attached to the bar via a steel hook. The strap was positioned around the subject's ankle and the foot plate adjusted so that each subject exerted a quadriceps contraction with the lower leg at a 110°

position with respect to the thigh. Care was taken to position the strap in the same position from day to day. For the jaw contractions, a bite block was devised consisting of two aluminum plates onto which strain gauges were mounted. The plates were covered with rubber-like material for cushioning and the entire block covered with changeable latex covers to assure cleanliness between subjects. The height of the bite block assembled in this way was 2.5 cm. Subjects used polyethylene mouth guards to protect their teeth. The initial phases of training used this bite-block but it became evident that subjects found the device very difficult to tolerate. There was excessive salivation, with some subjects choking and stopping contractions before fatigue occurred. In addition, some subjects were unable to utter intelligible words with the bite block in their mouths.

This method was altered so that subjects exerted jaw contractions without the bite-block using the protective mouth guards alone. Tension was determined from the EMG signal generated (see below, section 3b p. 5 - Methods). Fatigue was also determined from the change in the EMG signal (see below, section 4 p. 20 - Results).

During the training session, the subject exerted 2 maximum voluntary contractions (MVC) for each muscle group; these were 3 min apart. For the handgrip, sustained contractions were exerted at either 25, 40 or 70% MVC to fatigue. Fatigue was defined as the point when subjects were unable to hold the target tension. Three consecutive contractions at any given level of the tensions were performed with 3 min rest between contractions. Subjects were considered trained when the MVCs were within $\pm$ 5% of each other, and the duration of the first of the sustained contractions at a given tension was within ± 5%.

The same procedures and conditions were applied to the quadriceps contractions as described above for the handgrip. Sustained contractions were exerted at 25, 50 and 70% MVC. In addition, the same procedures were used for jaw contractions, exerted at 55 or 70% MVC.

Subjects also trained to performed intermittent isometric contractions that were 12-15 sec each in duration with 12-15 sec of rest between consecutive contractions. Handgrip, quadriceps or jaw contractions were exerted at 60, 70 or 85% MVC. The same procedures and conditions for fatigue were applied during intermittent contractions as described above for sustained contractions.

In addition to performing isometric contractions, subjects practiced the L-1 straining maneuvers while sitting in the "pilot's chair" used in a previous study (Williams et al AAMRL-TR-87-049). All training and experiments were conducted with the seatback angle at 30°.

3. Physiological Measurements:

a) ECG Standard limb-lead I configuration was used to record the electrocardiogram from subjects on a Grass Model 7 polygraph for 30 sec prior to the experimental procedure (see below, paragraph 4) and 30-60 sec following the procedure. Heart rates were calculated from 5 sec intervals during these periods and expressed as beats$\cdot$min^{-1} (bpm).

b) Electromyography (EMG) The EMG was recorded from the surface of the skin over the right intercostals between the 5th-6th intercostal spaces or over either the center of the quadriceps on the leg performing the contraction, or the forearm flexors, on the inner surface of the arm contracting, or the masseters. The skin was prepared by scrubbing the surface with acetone. Self adhesive silver-silver chloride electrodes were placed over the designated muscle groups, and care was taken to place the electrodes in the same spot during repeated experiments. Electrodes were attached to a pre-amplifier (Teca model PA62T) and then connected into an electromyograph (Teca model M). The raw EMG signal was displayed on an oscilloscope and simultaneously fed into a root mean squared (rms) converter (Analog Devices). The integrated signal was recorded on a Fisher Recordall. Subjects were instructed to remain quiet and relaxed prior to the given procedure. Since the EMG was negligible during these resting periods, it was taken as the baseline and set at zero signal height. The change in muscular activity due to the L-1 maneuver and or isometric muscular contraction was measured as the change in the height (in cm) of the integrated EMG signal. Typically, a 1 cm deflection was equivalent to 7.8 microvolts.

c) Arterial Blood Pressure (BP) Direct measurement of arterial blood pressure was made through a catheter inserted percutaneously into the radial artery. Sterile procedures were followed by first cleansing the catheterization field with alcohol and then betadine. The area was anaesthetized by a subcutaneous injection of 2% lidocaine. A teflon catheter unit was filled with sterile heparinized saline and inserted into the radial artery percutaneously using a 20g needle. Once entry was made into the artery, the needle was withdrawn and the catheter was connected to a constant-flow sterile heparinized saline drip (3ml/hr) and to a Statham-Gould pressure transducer (P23b) by way of a sterile 3-way stopcock. The catheter was secured in place with non-allergenic surgical tape. Baseline for the pressure signal was positioned prior to the insertion of the catheter with the fluid-filled system and calibration of the catheter-transducer assembly was made prior to the insertion of the catheter. Once the catheter was inserted, the calibration was rechecked to assure that the baseline had not shifted. The baseline was checked a final time at the end of the experiment for each subject. The arm was positioned so that the catheter and transducer were at heart level.

The pressure pulse was recorded continuously during the experimental period on a Grass model 7 polygraph and measurements of BP were taken 30 sec prior to and during regular intervals during the experimental procedure, as well as 30-60 sec following the completion of a procedure. During the L-1 maneuver alone, BP was measured at the beginning and end of each 5-sec segment of straining. During isometric contractions, BP was measured at 25, 50, 75 and 100% duration fatigue. Time scales were normalized to these periods since the endurance time (time to fatigue) was not the same for each subject or muscle group. Mean blood pressure (MBP) was recorded from an integrated signal from the pressure pulse and also checked by calculation from the diastolic plus one-third of the pulse pressure, read from the pressure signal.

4. Experimental Protocol

Each subject carried out the experiment twice, with the combination of straining maneuvers and contractions assigned randomly in each case. There was a minimum of 2 weeks allowed between experiments (and the arterial catheterization). Four days recovery was allowed after the first experiment, after which subjects maintained a training protocol until their second experiment.

On the day of the experiment, the sets of ECG and EMG electrodes were applied to the subjects. The subject was positioned into the "pilot's" chair with the seatback fixed at an angle of 30° and the thigh to leg angle at 110°. Each subject exerted 2 maximum voluntary contractions (100% MVC) for the handgrip, leg and jaw muscles, with the EMG signal recorded for each. There were 3 min allowed between each MVC for a given muscle group. The intra-arterial catheter was inserted into the radial artery of the non-contracting arm, and the arm positioned so that blood pressure would be measured at heart level. Subjects rested 15 min before beginning the experimental protocol. The combinations of procedures used for the experiments were:

<u>Experimental Procedure</u>

Condition 1	L-1 straining maneuver alone
Condition 2	Isometric handgrip contraction to fatigue (sustained and intermittent)
Condition 3	Isometric jaw contraction to fatigue (sustained and intermittent)
Condition 4	Isometric leg contraction to fatigue (sustained and intermittent)
Condition 5	L-1 maneuver with isometric handgrip contraction (sustained and intermittent)
Condition 6	L-1 maneuver with isometric jaw contraction (sustained and intermittent)
Condition 7	L-1 maneuver with isometric leg contraction (sustained and intermittent)

A matrix illustrating the order of the various combinations of L-1 and isometric contractions is given:

Experiment #1 - Sequence

Subject (A)	2	1	3	6	4	5	7
(B)	4	3	1	7	2	5	6
(C)	5	7	4	3	1	6	2
(D)	4	2	6	5	3	7	1
(E)	1	3	2	6	5	4	7
(F)	7	5	1	3	6	2	4
(H)	3	6	7	4	2	1	5
(I)	4	2	6	5	3	7	1
(J)	1	3	6	5	4	7	2

Experiment #2 - Sequence

Subject (A)	5	7	2	1	3	6	4
(B)	2	1	3	6	4	5	7
(C)	3	6	7	4	2	1	5
(D)	3	6	7	4	2	1	5
(E)	4	3	1	7	2	5	6
(F)	1	3	6	5	4	7	1
(H)	4	2	6	5	3	7	1
(I)	5	7	2	1	3	6	4
(J)	3	6	7	4	2	1	5

For the procedures involving the L-1 maneuver, subjects were given a countdown, instructed to initiate the straining and at the 5-sec and 10 sec mark to take a breath and to generate a straining effort again. They were given a signal to stop the maneuver at the 15 sec mark. Observation of the subjects and the EMG signal from the intercostals assured that each effort after the breath at 5 and 10 sec was consistent with the first. Subjects performed 6 sequential L-1 maneuvers, with 1-5 min between each. Subjects were instructed and reminded to keep the catheterized arm as relaxed as possible to avoid any artifact in the pressure pulse signal that might occur as a result of muscular tensing of the arm. In a previous study (1) utilizing the same procedures, EMG was measured from the catheterized resting arm of 9 subjects. As reported, the tensing that occurred was minimal and did not interfere with the recording of the pressure pulse signal. When subjects were asked to tense their catheterized arm, the HR changed by 13 ± 7 bpm above resting levels and MBP by 10-13 ± 5 mmHg above resting levels (see Fig. 12, ref. 1). A variable resting period, usually between 1-5 min, was permitted following the completion of a procedure to allow BP to return to resting conditions before the next procedure was performed.

5. Data Analysis

The values for HR, MBP and EMG were averaged for each subject for each procedure listed above and combined for both experiments to arrive at the average value reported. Values reported are the mean ± SEM. Significance was determined from analysis of variance for paired data and was achieved when $P < 0.05$. When significance was determined, a post-hoc Bonferoni test was applied to the data.

RESULTS

1. <u>Cardiovascular changes during the L-1 maneuver</u>

Figure 1 is a section of a tracing from one of the subjects illustrating the changes in the pressure pulse and MBP that occur during A) the L-1 maneuver, B) isometric exercise (in this case, a handgrip contraction sustained to fatigue) and C) an L-1 maneuver combined with isometric handgrip exercise. There is an immediate increase in both the systolic and diastolic pressures upon the initiation of the L-1 maneuver (Fig. 1A), but during the first 5 sec, BP gradually declines. During the reapplication of the straining, after the subject takes in a deep breath, BP is stabilized at a higher than resting level, but lower than the initial high levels during the beginning of the L-1. During the last 5 sec of the L-1, BP recovers somewhat, usually at higher levels than those achieved during seconds 5-10. After the release of the L-1 maneuver, there is a significant increase in the pulse pressure and a slowing of the HR. This pattern is typical of the cardiovascular responses during the L-1, as previously described (Williams et al, 1987), and is reminiscent of the adjustments made for a Valsalva maneuver. Figure 1B shows the gradual increase in BP during fatiguing isometric exercise. Peak levels are achieved at fatigue, when the subject is unable to maintain the targeted tension. During fatiguing isometric exercise, there is some chest-fixation and brief (1-3 sec) periods of breath-holding (Williams and Lind, 1987). When the L-1 maneuver is combined with isometric exercise (Fig. 1C) higher levels of BP were achieved during the 5-10 and 10-15 sec periods of the maneuver. Pulse pressure was maintained, unlike the L-1 maneuver alone, when the pulse pressure declined. This can be seen by comparing the pressure pulse signals in Fig. 1A to Fig. 1C.

Figure 2 shows the changes in systolic and diastolic blood pressure (panel A) as well as the changes in mean blood pressure (panel B) when the L-1 maneuver is exerted. Values given are the average from 9 subjects exerting 5 consecutive L-1 maneuvers ± SEM. During the first 5 sec of the L-1, systolic blood pressure (SBP) decreases significantly from 246 ± 2 to 182 ± 4 mmHg ($P < 0.0005$). SBP recovers to 190 ± 3 mmHg during seconds 5-10, but during this period, decreases again to 174 ± 3 mmHg ($P < 0.005$). During the last phase of the L-1 maneuver (from 10-15 sec), SBP increases back to 203 ± 4 mmHg (at 10 sec) and remains fairly constant, at 197 ± 3 mmHg (at 15 sec). These levels were not significantly different ($P < 0.15$). Diastolic blood pressure (DBP) followed a similar pattern of change, as seen in Fig. 2A. The DBP decreased significantly from 184 ± 2 to 142 ± 3 mmHg during 0-5 sec of the L-1 maneuver ($P < 0.0005$). It remained fairly constant during the 5-10 sec period of the maneuver, at 142 ± 3 to 138 ± 2 mmHg ($P < 0.15$) and then increased slightly to 152 ± 3 at 10 sec, and remained constant at 156 ± 1.0 mmHg ($P < 0.10$). The difference in the SBP between the level achieved initially, at 0 sec (246 ± 2 mmHg) versus that by the end of the L-1 maneuver, at 15 sec (198 ± 3 mmHg) was highly significant ($P < 0.0005$); similarly, the decrease in the DBP between the beginning and end of the L-1 was significant ($P < 0.0005$).

Figure 2B shows the changes in mean blood pressure (MBP) during the L-1 maneuver. At the onset of the L-1, MBP increased to 205 ± 1.5 mmHg but then decreased significantly to 155 ± 2.5 mmHg by 5 sec ($P < 0.0005$). During the 5-10 sec period of the L-1, MBP went from 158 ± 3 (at 5 sec) to 150 ± 2 mmHg (at 10 sec) ($P < 0.05$). The MBP recovered to 170 ± 3.5 mmHg and remained essentially constant at this level for the last 5 sec of the L-1 maneuver. The difference between the MBP at the beginning of the maneuver, 205 ± 1.5 mmHg, and the end of the maneuver, 169 ± 1.0 mmHg, was significant ($P < 0.0005$).

2. Cardiovascular Changes during Isometric Exercise

Figure 3 shows the changes in MBP (panel A) and HR (panel B) that occurred during sustained fatiguing isometric contractions for the handgrip, quadriceps and jaw. Contractions for each muscle group were exerted at 70% MVC. The duration of the sustained handgrip contractions (to fatigue) was 38 ± 3 sec; the duration of the sustained quadriceps contractions was 49 ± 3 sec, while the duration of the sustained jaw contractions was 28 ± 2 sec. For the handgrip contraction, MBP increased from resting levels of 115 ± 2 to fatigue levels of 190 ± 5 mmHg ($P < 0.0005$). For the quadriceps contraction, MBP increased from resting levels of 113 ± 7 to fatigue levels of 192 ± 9 mmHg ($P < 0.0005$). For the jaw contraction, MBP increased from resting levels of 118 ± 2 to fatigue levels of 168 ± 6 mmHg ($P < 0.0005$). There was no significant difference between the fatigue MBP for the handgrip versus the fatigue MBP for the quadriceps contractions ($P > 0.40$); however, the MBP at fatigue for the jaw contraction was significantly lower than that for the handgrip contraction ($P < 0.0125$). While not directly measured in this study, any tensing from other muscle groups would only contribute about 10-15 mmHg of the increase in mean arterial pressure during fatiguing contractions, (1, 3).

Figure 3B illustrates the changes in HR that occurred during these contractions. The HR at fatigue during the handgrip contractions were significantly higher than the HR at rest ($P < 0.0005$); likewise, the HR at fatigue during the quadriceps contractions were significantly higher than resting HR ($P < 0.0005$). Unlike the MBP at fatigue, there was a significant difference between the peak HR achieved at fatigue in response to handgrip versus quadriceps contractions ($P < 0.05$). The peak HR at fatigue for the jaw contractions were significantly different from both the HR during the handgrip ($P < 0.0005$) and quadriceps ($P < 0.0005$).

The cardiovascular changes that occurred when isometric contractions were performed in an intermittent fashion are illustrated in Figure 4. In this procedure, the contractions were sustained for 15 sec, followed by 15 sec of rest, when another contraction was exerted, and so on with this sequence of consecutive contractions interspersed by brief rest periods until the subjects were either unable to generate the target tension or maintain the target tension for the required 15 sec. The time sequence of 15 sec "on", 15 sec "off" (rest) was chosen because of the duration of the L-1 maneuver. Contractions for each of the muscle groups were exerted at 70% MVC. The average number of contractions exerted in this way for the handgrip muscles was 5 ± 0.5 (for a total exercise time of 135 sec); for the leg muscles, 6 ± 0.5 (for a total exercise time of 165 sec); for the jaw muscles, 4 ± 0.3 (for a total exercise time of 105 sec). Figure 4A shows the changes in MBP that occurred during these intermittent fatiguing contractions. In all cases, the MBP at fatigue was significantly higher than the resting levels of MBP ($P < 0.0005$). The MBP at fatigue for the intermittent quadriceps contractions was not significantly different than the MBP achieved at fatigue during intermittent handgrip contractions ($P < 0.3$); however, the MBP at fatigue for the jaw muscles was significantly lower ($P < 0.0005$) than the MBP at fatigue for the handgrip contractions. The MBP achieved at fatigue for any of the given muscle groups were the same, regardless of whether the contractions were performed in a sustained or intermittent fashion.

Figure 4B shows the changes in HR that occurred during fatiguing intermittent contractions. There was a significantly higher HR at fatigue, compared to resting levels, for each of the muscle groups ($P < 0.0005$). The peak HR achieved at fatigue for the handgrip exercise was not significantly different from the peak HR measured at fatigue for the quadriceps contractions ($P < 0.15$); however, the HR at fatigue for the jaw contractions was significantly lower than those measured for the handgrip contractions ($P < 0.0005$).

3. <u>Cardiovascular changes during combined L-1 maneuvers and isometric exercise</u>

The changes in systolic and diastolic pressures that were measured when subjects performed sustained isometric handgrip contractions at 70% MVC while simultaneously exerting successive L-1 maneuvers are shown in Figure 5A. While the general pattern of response is similar to that shown for the L-1 maneuver alone (see Fig. 2A), there are differences that occurred as a result of the high intensity isometric exercise being exerted simultaneously. While the SBP dropped by some 37 mmHg during the first segment of the L-1 maneuver, from 0 to 5 sec, ($P < 0.01$), this drop was less than the 64 mmHg drop when the L-1 maneuver alone was performed ($P < 0.05$). This appears to be due to a higher SBP at the 5 sec mark when the handgrip contraction was applied, since the initial SBP were the same in both conditions. The absolute SBP at the 5-10 sec segment with the handgrip contraction were higher than the SBP measured during the L-1 alone by some 20 mmHg ($P < 0.10$). The largest effect of the added isometric contraction was seen during the last part of the L-1 maneuver at 10-15 sec. Here, SBP increased by almost 20 mmHg while the handgrip was applied ($P < 0.01$) and the absolute levels of SBP at this time were 30 mmHg higher at the 10 sec mark ($P < 0.01$) and almost 50 mmHg higher at the 15 sec mark, the end of the L-1 maneuver ($P < 0.0005$).

A similar pattern emerged for the MBP when handgrip contractions were applied simultaneously with the L-1 maneuver, as shown in Figure 5B. While the initial MBP at the beginning of the L-1 maneuver and contraction were the same (compare to Fig. 2B) at 205 $\pm$ 1 versus 201 $\pm$ 9 mmHg, respectively, the MBP by the 5 sec mark was significantly higher with the simultaneous handgrip (171 $\pm$ 5 vs 155 $\pm$ 2 mmHg, $P < 0.025$). The drop in the MBP over the first 5 sec of the L-1 maneuver, 50 $\pm$ 2 mmHg, was significantly greater than the fall in MBP during the same segment (30 $\pm$ 7 mmHg) when the handgrip contraction was applied ($P < 0.05$). The MBP at the 5-10 sec segment were higher with the handgrip contraction (165 $\pm$ 5 vs 150 $\pm$ 2, $P < 0.025$). Additionally, the MBP at the final segment of the L-1 maneuver was increasing with the handgrip contraction and was significantly higher at both the 10 sec mark (190 $\pm$ 4 vs 170 $\pm$ 3, $P < 0.005$) and at the 15 sec mark (205 $\pm$ 6 vs 170 $\pm$ 1 mmHg, $P < 0.0005$).

Table 2 indicates that the handgrip contraction also enhanced the HR during the L-1 maneuver. Heart rates were significantly higher with the added isometric contraction at the 0-5 sec period and the 10-15 sec period when compared to the L-1 maneuver alone.

The influence of performing a sustained isometric contraction of the quadriceps with the L-1 maneuver is presented in Figure 6. As with the simultaneous handgrip contraction and L-1 maneuver, isometric contraction of the quadriceps resulted in the same general pattern of response. The initial SBP achieved during this procedure (271 $\pm$ 20 mmHg) was not significantly higher than the initial SBP achieved with the L-1 maneuver alone, 245 $\pm$ 2 mmHg ($P < 0.10$), and the decrease in SBP that occurred over the first 5 sec of the procedure with the leg contraction, 50 $\pm$ 8 mmHg, was slightly less than the decrease that occurred with the L-1 maneuver alone ($P < 0.10$). The initial SBP achieved during the L-1 with the quadriceps contraction was not significantly higher than the initial SBP achieved with the L-1 and the handgrip contraction ($P < 0.10$). The SBP during the middle segment of the L-1 maneuver (5-10 sec) was significantly higher than during the L-1 maneuver alone ($P < 0.05$ at 5 sec and $P < 0.025$ at 10 sec). The SBP at this segment with the simultaneous leg contraction was not significantly different than the SBP achieved with simultaneous handgrip contraction. The SBP during the last 5 sec of the L-1 maneuver was significantly higher with the simultaneous quadriceps contraction ($P < 0.0005$) than with the L-1 maneuver alone but not significantly different than the final SBP achieved when the handgrip isometric exercise was combined with the L-1 maneuver ($P > 0.25$).

The MBP achieved when an isometric quadriceps contraction was combined with the L-1 maneuver was higher than those measured during the L-1 alone, as shown in Fig. 6B. As with the handgrip contraction, while the initial MBP was similar, by the 5 sec mark, the MBP was significantly higher ($P < 0.05$) when the quadriceps contraction was added. Thereafter, the MBP was significantly higher at the 10 sec mark ($P < 0.025$) and at the end of the L-1 procedure ($P < 0.0025$) when the quadriceps were contracting simultaneously. The MBP achieved at the end of the L-1 maneuver with the quadriceps contraction, 203 $\pm$ 6 mmHg, was not different than the MBP achieved at the end of the L-1 maneuver with the handgrip contraction, 205 $\pm$ 6 mmHg, as seen in Fig. 5B.

The HR generated during the simultaneous quadriceps contraction and L-1 maneuver were significantly higher than those acnieved with the L-1 maneuver alone during every segment of the procedure, as shown in Table 2. None of the HR with the quadriceps contraction were different from the HR measured during the simultaneous handgrip contraction and L-1 maneuver.

The effects of exerting an intermittent isometric contraction with the jaw muscles simultaneously with the L-1 maneuver are presented in Figure 7. The initial SBP with the jaw contraction, 243 $\pm$ 11 mmHg was not different from the initial SBP achieved with the L-1 maneuver alone or when isometric contractions of the handgrip or quadriceps were applied. The SBP at the 5 sec mark, 202 $\pm$ 11 mmHg, was not higher than the SBP during the L-1 maneuver alone ($P > 0.10$). The SBP during the middle segment of the L-1 maneuver with the jaw contraction was some 30 mmHg higher than the L-1 maneuver alone ($P < 0.01$). This level of SBP was not different from the levels achieved when the L-1 maneuver was combined with either the handgrip or quadriceps contraction (F-ratio, 0.928). The SBP at the end of the L-1 with the isometric jaw contraction, 229 $\pm$ 10 mmHg, was significantly higher than the SBP at the end of the L-1 maneuver alone ($P < 0.025$). The SBP with the jaw contraction was not different than levels achieved with the other forms of isometric contractions (F-ratio, 1.098).

The initial MBP with the simultaneous jaw contraction, 200 ± 13 mmHg, was not significantly different from the initial MBP with the L-1 maneuver alone ($P > 0.35$), and not different from those levels achieved with the other types of isometric contractions (F-ratio, 1.222). The MBP by the 5 sec mark, 170 ± 10 mmHg, was not significantly higher than the MBP achieved during this time with the L-1 alone ($P > 0.10$). This is unlike the effects of the handgrip and leg contractions which did significantly elevate the MBP at this time. The MBP by the middle segment of the L-1 procedure was significantly higher with the isometric jaw contraction ($P < 0.025$) than the levels achieved with the L-1 maneuver alone. Additionally, the MBP at the end of the L-1 procedure with the jaw contraction was some 20 mmHg higher than the L-1 maneuver alone ($P < 0.05$). The peak MBP achieved at the end of the L-1 maneuver with the jaw contraction was not significantly different from those levels achieved with either the simultaneous handgrip or quadriceps contractions (F-ratio, 1.300).

The changes in HR that occurred with the simultaneous jaw contraction are presented in Table 2. While HR were higher from resting levels during the combined L-1 and jaw contraction, none of the HR were higher than the corresponding levels during the same segments during the L-1 maneuver alone.

The changes in MBP during L-1 maneuvers with isometric contractions are summarized in Figure 8. As can be seen, upon the onset of the L-1 maneuver, MBP reached similar levels regardless of which muscle group was engaged in simultaneous isometric contraction. Each muscle group was effective in keeping the MBP significantly elevated above the level generated by the L-1 maneuver alone by the 5-sec mark of the procedure. Similarly, isometric contractions were effective in maintaining a significantly higher MBP between the 5-10 sec period, and even more so during the last 5 sec period of the L-1 maneuver. Isometric contractions of both the handgrip muscles and the quadriceps generated higher MBP than contractions of the jaw muscles at the end of the L-1 maneuver.

4. EMG Changes during L-1 Maneuvers

Figure 9 shows the changes in the rectified EMG signal during simultaneous isometric contractions with the L-1 maneuver. The amplitude of the rectified signal for both the handgrip contractions and the quadriceps contractions increase by the same increment, approximately 5 cm (relative units). This increment is characteristic of a fatiguing contraction. The height of the quadriceps signal is greater than the height of the handgrip or jaw signal due to the muscle mass involved. Likewise, the greater EMG signal recorded from the handgrip muscles reflects a larger muscle mass than the jaw muscles. While both the quadriceps and handgrip signals progressively increased as the contractions continued during successive L-1 maneuvers, the signal recorded from successive jaw contractions decreased slightly. Subjectively, the volunteers perceived their jaw muscles were fatigued after a certain number of contractions (range 5-14 contractions at maximal effort) and stopped the simultaneous contractions and L-1 maneuvers. The EMG signal from the intercostals, which was recorded in all experiments, increased upon the initiation of the L-1 maneuver and then remained constant for the 15 sec period of straining. This signified no decrement in the effort to exert the L-1 maneuver. There was no influence on the EMG signal of the intercostals from any of the isometric contractions, i.e., addition of the isometric contractions did not alter either the height of the initial intercostal signal nor the signal recorded during the L-1 maneuver with the simultaneous isometric contraction from the EMG signals recorded during the L-1 maneuver alone.

DISCUSSION

The objective of this study was to determine whether simultaneous performance of high intensity isometric muscular contractions with L-1 straining maneuvers would result in higher arterial pressures than the L-1 maneuver alone. Higher pressures resulting from this procedure might enable pilots to withstand higher +Gz forces. The need to protect pilots from reduction or loss of vision or loss of consciousness during high +G acceleration has been recognized for a long time. Compromises in vision and consciousness arise from undesirable alterations in cardiovascular function and the principal sources of the problem have been identified as a reduction of blood pressure to the head which results in an insufficient blood flow that first affects vision and then consciousness, and secondly, pooling of blood in the capacitance vessels in the lower regions of the body as a result of the alterations in the hydrostatic pressures along the longitudinal axis of the body. The two events are separate but interrelated. During periods of high +G stress, pilots exert straining maneuvers such as the L-1 or M-1 to raise the blood pressure to counteract the falling arterial pressure. The L-1 maneuver uses tensing of abdominal regions and in general, the whole body, with a Valsalva maneuver against a totally closed glottis (4). The L-1 procedure uses 3 consecutive rapid straining maneuvers, each held for 5 sec. In addition, anti-gravity (G-suits) trousers are inflated to try to prevent the sequestering of blood in the lower extremities (5, 6). Both procedures enhance the G-tolerance of pilots so that levels of 6-8 +Gz can be withstood for brief periods. A previous study indicated that during the L-1 straining maneuver, the peak of the mean blood pressure was achieved at the onset of the procedure when subjects performed the L-1 in a fairly upright position, at +1G, with the seatback angle of their pilot chair apparatus at 30° (1, 7). This amounted to pressures ranging from 190-195 mmHg, thus generation of the L-1 maneuver by well-motivated and trained subjects should permit tolerance of +5 to +6 Gz without the aid of anti-G suit. However, within the first 5 sec period of the L-1 maneuver, the mean blood pressure fell by some 30-35 mmHg, amounting to the loss of 1 G tolerance (1, 7). Thus, even within 5 sec of sustained Valsalva, compromises are imposed on the cardiovascular system which may not allow the pilot adequate acceleration protection, if that acceleration profile is sustained longer than 5 sec. This prompted the present study.

Our results indicate that application of high intensity isometric contractions significantly elevated the arterial pressure above levels generated by L-1 straining maneuvers alone (see Fig. 8). The increments in the arterial pressure were most prevalent after the onset of the L-1 maneuver resulting in less of a fall in the mean blood pressure during the 5 sec segments of the maneuver, and substantially higher levels of mean pressure overall during the later phases of the L-1 (i.e., the periods 5-10 sec and then 10-15 sec). The increments in arterial pressure were similar, regardless of the muscle group used, provided each contraction was of high enough intensity to induce fatigue of the contracting muscle in a relatively short time (within 30-60 sec). The muscle groups tested in this study were the jaw, the quadriceps and the forearm (handgrip) flexors.

As with the previous study, all experiments carried out in this project were performed at 1 Gz. In the present set of experiments, all subjects were in an upright position (seatback angle at 30°) and none were wearing anti-G suits. Previously, this was determined not to make a difference in either the initial or end mean blood pressures or affect the esophageal pressures or heart rates generated during the L-1 maneuver when performed at +1G(1). The mean blood pressures achieved at the onset of the L-1 maneuvers, without additional high-intensity isometric contractions, averaged 205 $\pm$ 1.5 mmHg. This fell to 155 $\pm$ 2.5 mmHg within the first 5 sec, a drop of some 50 mmHg. These levels are comparable to those reported from a previous study (1, 7). The pattern of response in the blood pressure during the L-1 maneuver alone seen in this study is identical to that described previously (1, 7), and are characteristic of the changes that occur during the initial phases of a Valsalva maneuver (8). Maintenance of high intrathoracic and intra-abdominal pressures, which were measured during the L-1 maneuver (1), impede venous return within the first 5 sec of the L-1, causing the arterial pressure to fall during this initial segment of the straining effort, even though it remains above resting levels. The fact that the mean blood pressure remains stable during the middle segment of the maneuver, and then recovers some 20 mmHg during the final segment of the maneuver most likely reflects baroreceptor induced reflex changes in cardiovascular function (14, 15). Again, these data reflect that generation of the L-1 maneuver by well motivated and trained subjects should permit tolerance of +5 to +6 Gz without the aid of an anti-G suit under acceleration conditions.

The mean blood pressures generated initially at the onset of the L-1 averaged 200 $\pm$ 13 mmHg with the jaw, 216 $\pm$ 10 mmHg with the quadriceps and 201 $\pm$ 9 mmHg with the handgrip isometric contractions simultaneously applied. None of these levels were significantly higher than the initial mean pressure in response to the L-1 maneuver alone. Two factors are influencing this result. First, the initial increments in blood pressure are determined mainly by the effects of the straining, i.e., the Valsalva effects (8). Increases in airway pressure caused by forced expiration against a closed glottis produce simultaneous increases in abdominal and intrapleural pressures (8). These in turn are transmitted to the peripheral systemic arterial system producing corresponding increases in systolic and diastolic blood pressures. Secondly, during the onset of an isometric contraction, very little influence, if any, of the reflex alteration in cardiovascular function from skeletal muscle afferent nerve fibers (group III and IV) is operating to control the arterial pressure. This might be expected.

The benefit from performing high intensity, eventually fatiguing, isometric muscle contractions is seen after the initial part of the L-1 maneuver. During the first 5 sec of the L-1, the decline in mean blood pressure was significantly less than during the L-1 alone. During the mid portion of the L-1 maneuver (sec 5-10), the isometric contractions resulted in a significantly higher pressure by almost 20 mmHg, while during the last 5 sec of the L-1 maneuver, mean blood pressure averaged about 215 mmHg with either the quadriceps or handgrip contractions, and about 190 mmHg with the jaw contraction. This amounted to some 45 mmHg higher with the quadriceps or handgrip contractions and 20 mmHg higher with the jaw contraction. This pattern is in agreement with preliminary data reported previously from this laboratory (1). Additionally, Lohrbauer et al (9) reported higher mean eye-level arterial pressures during a rapid-onset G-acceleration by some 20 mmHg during a handgrip or during a handgrip and simultaneous G-suit inflation. These increments can be attributed to the effects of fatiguing isometric contractions. Two mechanisms are thought to be responsible for the pressor reflex elicited by isometric contractions. One component is known as "central command" which suggests that signals from higher brain centers are transmitted down to medullary cardiovascular centers. This together with brief periods of chest fixation are thought to contribute some 10-20 mmHg increment in the mean blood pressure during fatiguing contractions (3, 10).

The other component of the pressor reflex termed the "peripheral reflex component." During contraction of skeletal muscle small afferent nerve fibers, "ergoreceptors", (group III and IV, c-fibers) are activated. These synapse in medullary cardiovascular centers which in turn control autonomic activity that results in withdrawal of vagal tone and increases in sympathetic tone causing changes in heart rate and cardiac output. These circulatory alterations together with a mild peripheral vasoconstriction account for the increases in arterial pressure (see 10 for review). This component accounts for the remainder of the pressor response during fatiguing isometric exercise.

Both mechanisms as well as brief periods of straining, especially as the contraction becomes fatiguing, contribute to the increases in blood pressure during voluntary isometric exercise (3). The EMG data (see Fig. 9) indicate that both the quadriceps and handgrip contractions were fatiguing, signified by the same increment in the height of the rectified signal. These changes in the amplitude of the EMG signal are similar to those reported previously (11, 12). There was no change in the EMG signal recorded from the intercostals during the combined isometric exercise and the L-1 maneuvers in comparison to the L-1 maneuvers alone. This indicated there was no difference in the straining effort between experimental protocols, thus the greater arterial pressures or heart rates measured during the combined isometric contractions and L-1 maneuvers were not due to greater subject effort. The EMG signal during the jaw contractions actually decreased slightly, even though subjectively, subjects experienced the sensation of "fatigued" muscles. While exerting contractions with the jaw muscles did elevate arterial pressure (see Fig. 8), the increments were less than those recorded in response to either the leg or handgrip contraction, by some 20-25 mmHg. Others have measured increases in blood pressure in response to jaw muscle contraction (13), which prompted us to suggest this might be useful for pilots as a means of elevating arterial pressure during periods of high G-stress. However, while there was some benefit to consciously exerting contractions with the jaw, other factors must be taken into consideration. Earlier on in the study, jaw contractions were attempted with a bite-block device placed in the mouth. While this was done to increase resting muscle length, thus permitting greater levels of force to be achieved and inducing fatigue more rapidly and to allow actual recording of the forces developed, subjects clearly had trouble with excessive salivation and gagging. This would probably render the use of such a device under actual flight conditions inappropriate. Table 2 indicates that while the heart rate increased above resting levels during the combined jaw contraction and the L-1 maneuver, these levels were not any higher than the levels generated in response to the L-1 alone. Combined leg contractions or handgrip contractions with the L-1 maneuver clearly resulted in significantly higher heart rates than the straining maneuver alone. This leads us to conclude that the jaw contractions were not truly fatiguing, as suggested by the emg, but that the benefit from consciously contracting the jaw muscles made the straining effort more effective, by focusing the subjects' attention on the L-1 procedure.

Conclusions

Addition of high intensity isometric contractions, which rapidly induce fatigue of the target muscle, to L-1 straining maneuvers results in significantly higher arterial pressures than the straining maneuver alone. This increment can approach 45 mmHg during the last 5 sec segment of the L-1 maneuver, which affords an extra 1 to 1.5 G protection. Isometric contractions of either the handgrip muscles or the quadriceps were equally effective in generating higher arterial pressures. Contractions of the jaw muscles were less effective than the handgrip or leg contractions.

REFERENCES

1. Williams, C.A., J.E. Douglas, G. Miller, A. Karl, R.L. Wiley and A.R. Lind The relationship between changes in arterial pressure, esophageal pressure and the EMG of various muscle groups during the L-1 straining maneuver at different spine-to-thigh angles. **AAMRL-TR-87-059**, 1987

2. Clarke, R.S.J., R.F. Hellon and A.R. Lind Duration of sustained contractions of the human forearm at different muscle temperatures. J. Physiol **143**:454-473, 1958

3. Williams, C.A. and A.R. Lind The influence of straining maneuvers on the pressor response during isometric exercise. Eur. J. App. Physiol **56**:230-237, 2987

4. Shubrooks, S.J. and S.D. Leverett Effect of the Valsalva maneuver on tolerance to +Gz acceleration. J. Appl. Physiol **34**:460-466, 1973

5. Hrebien, L. and E. Hendler Factors affecting human tolerance to sustained acceleration. Aviat. Space Environ Med **56**:19-26, 1985

6. Bivins, H.G., R. Knopp, C. Tiernan, P.A.L. dos Santos and G. Kallsen Blood volume displacement with inflation of antishock trousers. Ann. Emer. Med **11**:409-412, 1982

7. Williams, C.A., A.R. Lind, R.L. Wiley, J.E. Douglas and G. Miller Effect of different body postures on the pressures generated during an L-1 maneuver. Aviat. Space Environ. Med **59**:920-927, 1988

8. Sharpey-Schafer, E.P. Effect of respiratory acts on the circulation. Handbook of Physiology Vol. 3 American Physiological Society, Bethesda, MD p. 1875-1886, 1965

9. Lohrbauer, L.A., R.L. Wiley, S.J. Shubrooks and M. McCally Effect of sustained muscular contraction on tolerance to +Gz acceleration. J. Appl Physiol **32**:203-209, 1972

10. Lind, A.R. Cardiovascular adjustments to isometric contractions: static effort. Handbook of Physiology - The Cardiovascular System III Chap. 26 The American Physiological Society, Bethesda, MD p. 947-966, 1984

11. Lind, A.R. and J.S. Petrofsky Amplitude of the surface electromyogram during fatiguing isometric contractions. Muscle and Nerve **2**:257-264, 1979

12. Petrofsky, J.S. and C.A. Phillips Discharge characteristics of motor units and the surface EMG during fatiguing isometric contractions at submaximal tensions. Aviat. Space Environ Med **56**:581-586, 1985

13. Forbes, J., L.M. Abbey, J.G. Burch and A.C. Segretti Cardiovascular responses to isometric and dynamic jaw-muscle exercises in man. Arch. Oral Biol. **24**:205-210, 1979

14. Wood, E.H., E.H. Lambert and C.F. Code Involuntary and voluntary mechanisms for preventing cerebral ischemia due to positive Gz acceleration. Physiologist **24**:Supplement S33-S35, 1981

15. Laughlin, M.H., J.W. Burns and M.J. Parnell Regional distribution of cardiac output in unanesthetized baboons during +Gz stress with and without an anti G suit. Aviat. Space Environ Med **53**:133-141, 1982

ACKNOWLEDGEMENTS

The authors wish to thank Drs. Robert Van Patten and Tracey Gordon from WPAFB and Mr. Al Karl, Jr. from Systems Research Laboratories for their input during this project.

Table 1

Anthropometric Summary of Subjects

Subject	Age (years)	Height (cm)	Weight (kg)
A	26	188	90.9
B	40	187	91.1
C	30	193	102.3
D	28	173	75.4
E	23	185	87.3
F	24	187	93.8
G*	--	---	-----
H	26	183	81.8
I	24	182	82.7
J	31	168	61.4
	28 ± 1.7	183 ± 2.4	85.1 ± 3.7

*Subject withdrew from study voluntarily
Values are mean ± SEM

TABLE 2

CHANGES IN HEART RATE DURING L-1 MANEUVERS IN COMBINATION WITH ISOMETRIC EXERCISE

Heart Rates (beats/min)

	Rest	A	B	C
L-1 Maneuver	87 ± 3	106 ± 3^{b}	116 ± 4^{c}	124 ± 3^{c}
L-1 Maneuver + Sustained Handgrip	90 ± 3	$130 \pm 9^{c,d}$	130 ± 7^{c}	$140 \pm 7^{c,e}$
L-1 Maneuver + Sustained Leg	90 ± 3	$136 \pm 5^{c,f}$	$139 \pm 5^{c,g}$	$139 \pm 6^{c,e}$
L-1 Maneuver + Intermittent Jaw	90 ± 4	112 ± 3^{a}	112 ± 4^{c}	132 ± 4^{c}

A $0 \rightarrow 5$ sec
B $5 \rightarrow 10$ sec
C $10 \rightarrow 15$ sec

a $P < 0.025$ from corresponding Rest
b $P < 0.005$ from corresponding Rest
c $P < 0.0005$ from corresponding Rest
d $P < 0.025$ from same time during L-1 maneuver alone
e $P < 0.05$ from same time during L-1 maneuver alone
f $P < 0.0025$ from same time during L-1 maneuver alone
g $P < 0.005$ from same time during L-1 maneuver alone

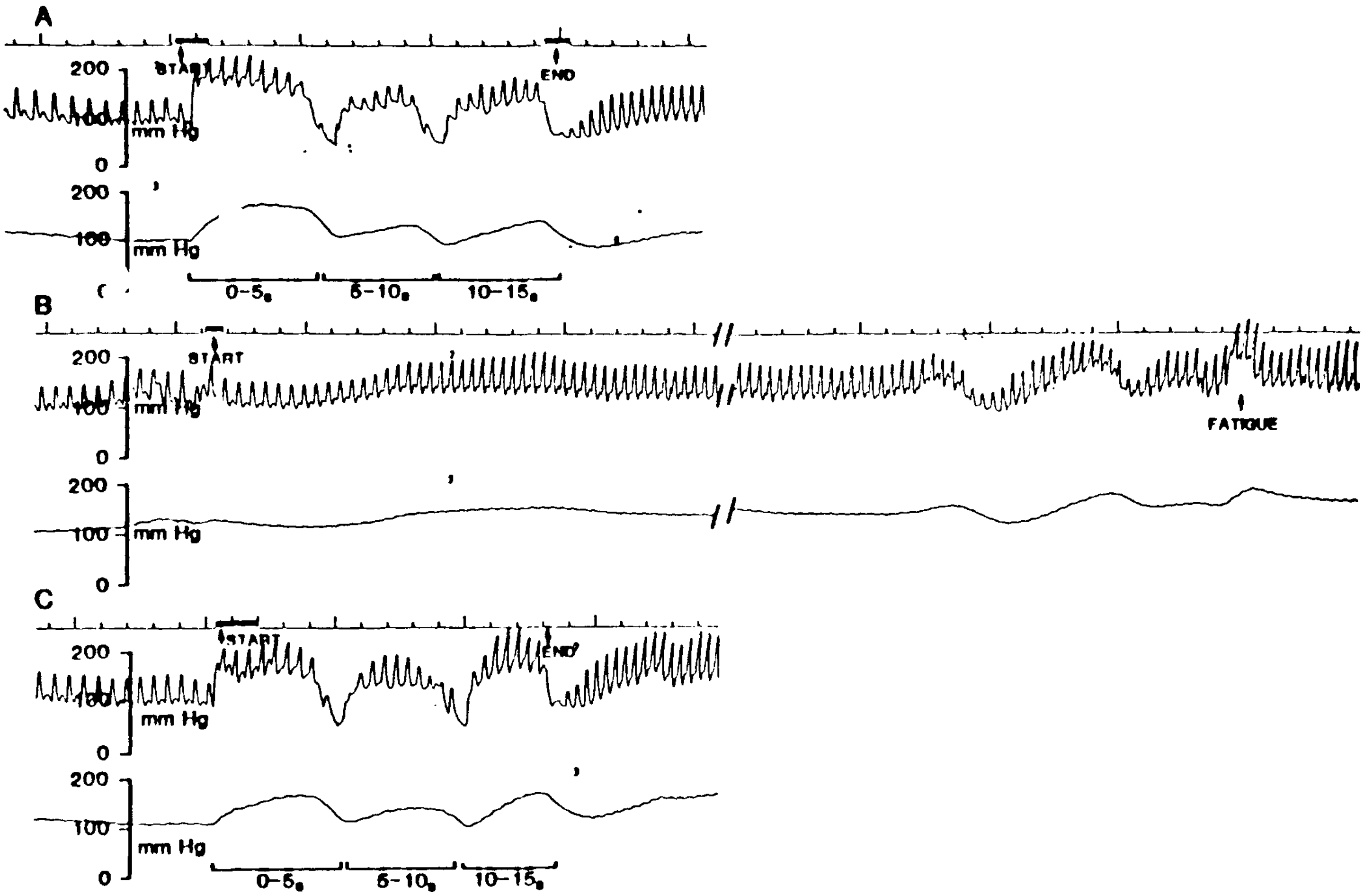

A
START
END
200
100
mm Hg
0
200
100
mm Hg
0-5s
5-10s
10-15s
B
START
FATIGUE
200
100
mm Hg
0
200
100
mm Hg
0
C
START
END
200
100
mm Hg
0
200
100
mm Hg
0
0-5s
5-10s
10-15s

Figure 1

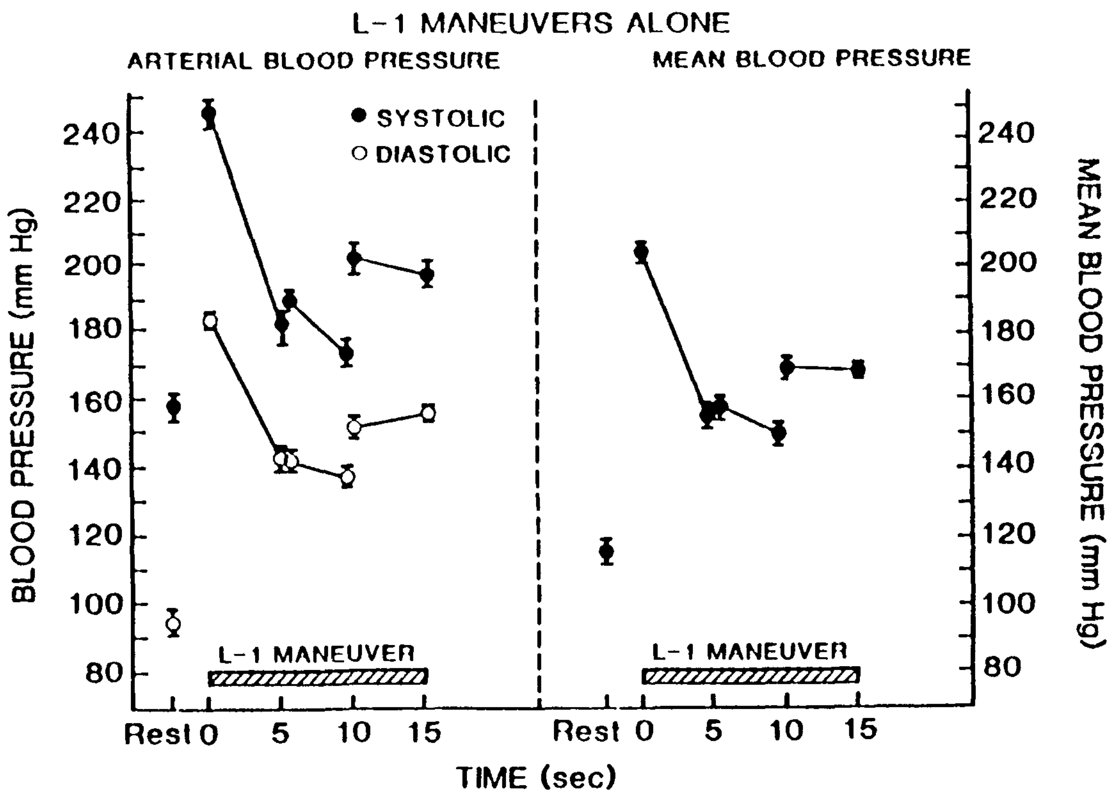

L-1 MANEUVERS ALONE
ARTERIAL BLOOD PRESSURE
MEAN BLOOD PRESSURE
● SYSTOLIC
○ DIASTOLIC
BLOOD PRESSURE (mm Hg)
MEAN BLOOD PRESSURE (mm Hg)
240
220
200
180
160
140
120
100
80
L-1 MANEUVER
L-1 MANEUVER
Rest 0 5 10 15
Rest 0 5 10 15
TIME (sec)

Figure 2

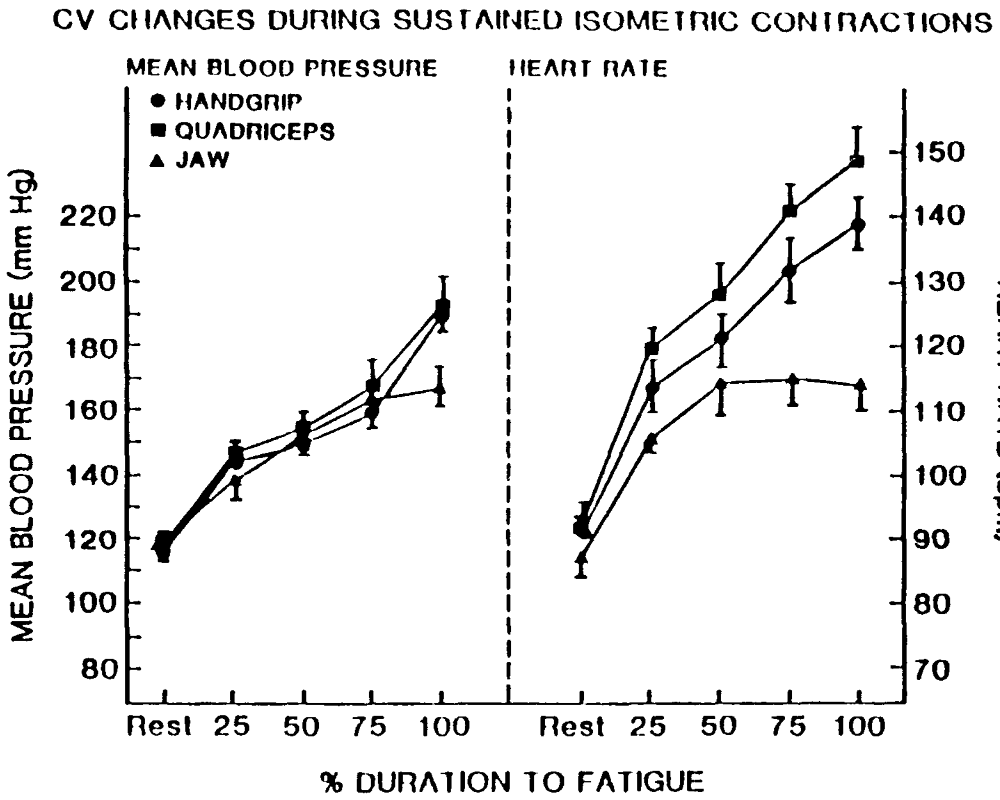
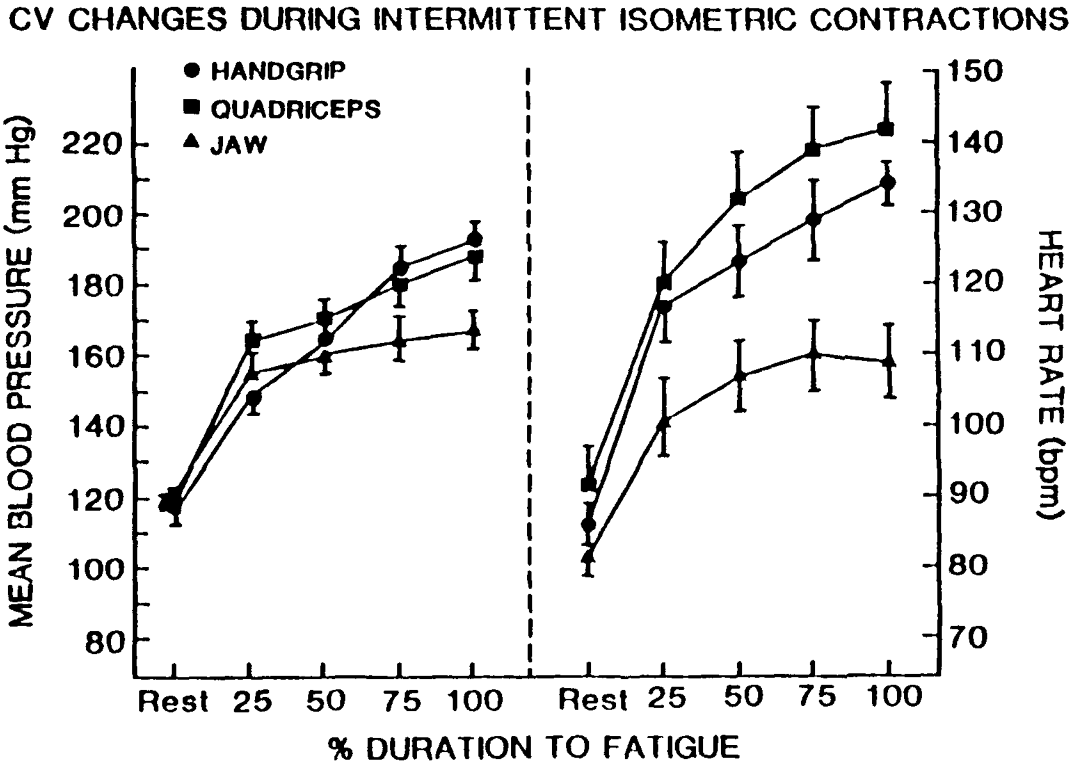
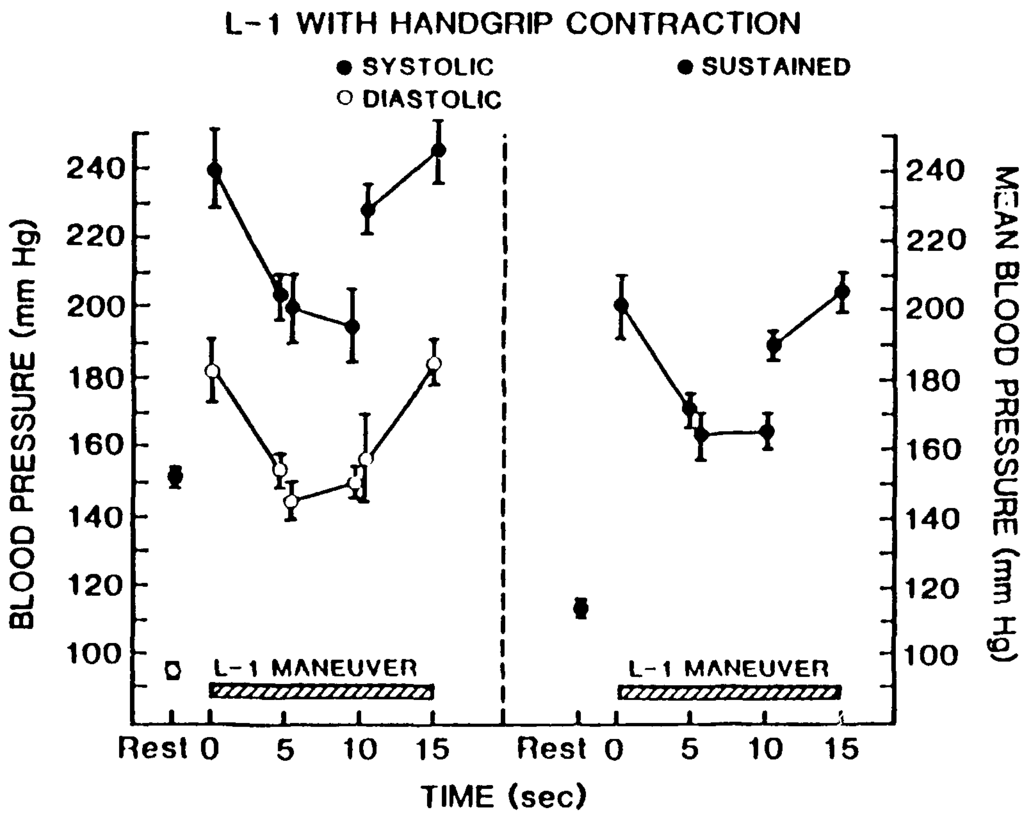

CV CHANGES DURING SUSTAINED ISOMETRIC CONTRACTIONS
MEAN BLOOD PRESSURE
HEART RATE
● HANDGRIP
■ QUADRICEPS
▲ JAW
MEAN BLOOD PRESSURE (mm Hg)
80
100
120
140
160
180
200
220
HEART RATE (bpm)
70
80
90
100
110
120
130
140
150
Rest 25 50 75 100
Rest 25 50 75 100
% DURATION TO FATIGUE

Figure 3



CV CHANGES DURING INTERMITTENT ISOMETRIC CONTRACTIONS
HANDGRIP
QUADRICEPS
JAW
MEAN BLOOD PRESSURE (mm Hg)
220
200
180
160
140
120
100
80
150
140
130
120
110
100
90
80
70
HEART RATE (bpm)
Rest 25 50 75 100
Rest 25 50 75 100
% DURATION TO FATIGUE

Figure 4



L-1 WITH HANDGRIP CONTRACTION
SYSTOLIC
DIASTOLIC
SUSTAINED
BLOOD PRESSURE (mm Hg)
MEAN BLOOD PRESSURE (mm Hg)
240
220
200
180
160
140
120
100
L-1 MANEUVER
L-1 MANEUVER
Rest 0 5 10 15
Rest 0 5 10 15
TIME (sec)

Figure 5

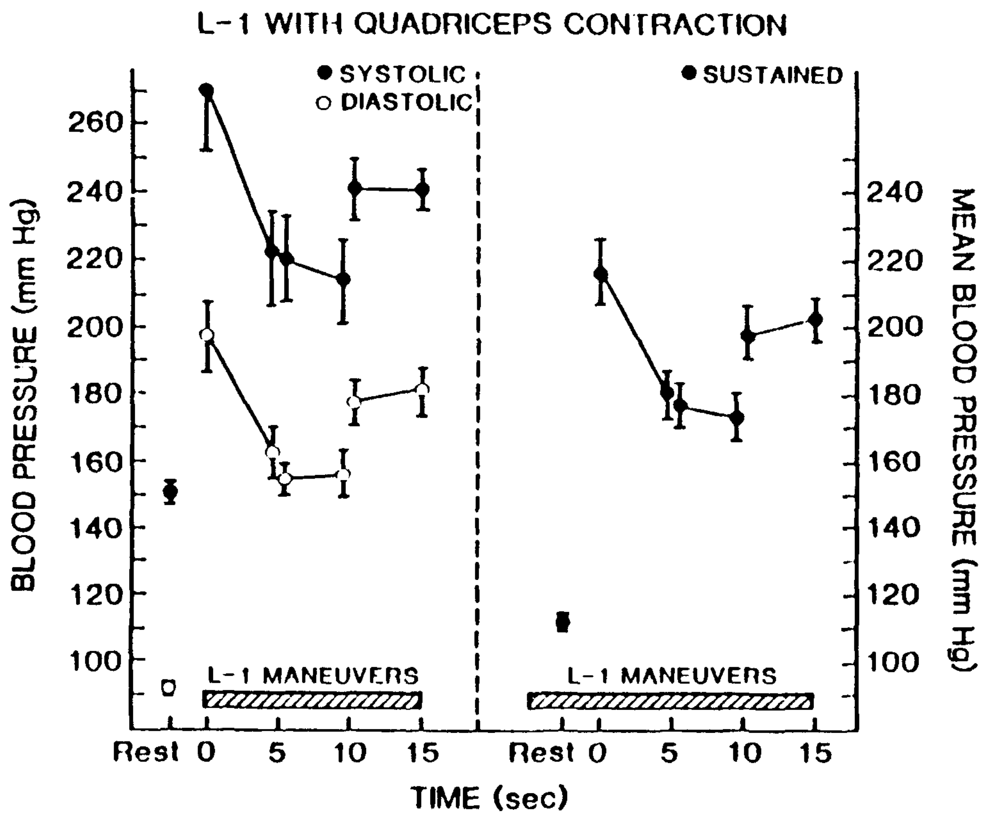

L-1 WITH QUADRICEPS CONTRACTION
● SYSTOLIC
○ DIASTOLIC
● SUSTAINED
BLOOD PRESSURE (mm Hg)
MEAN BLOOD PRESSURE (mm Hg)
260
240
220
200
180
160
140
120
100
L-1 MANEUVERS
L-1 MANEUVERS
Rest 0 5 10 15
Rest 0 5 10 15
TIME (sec)

Figure 6

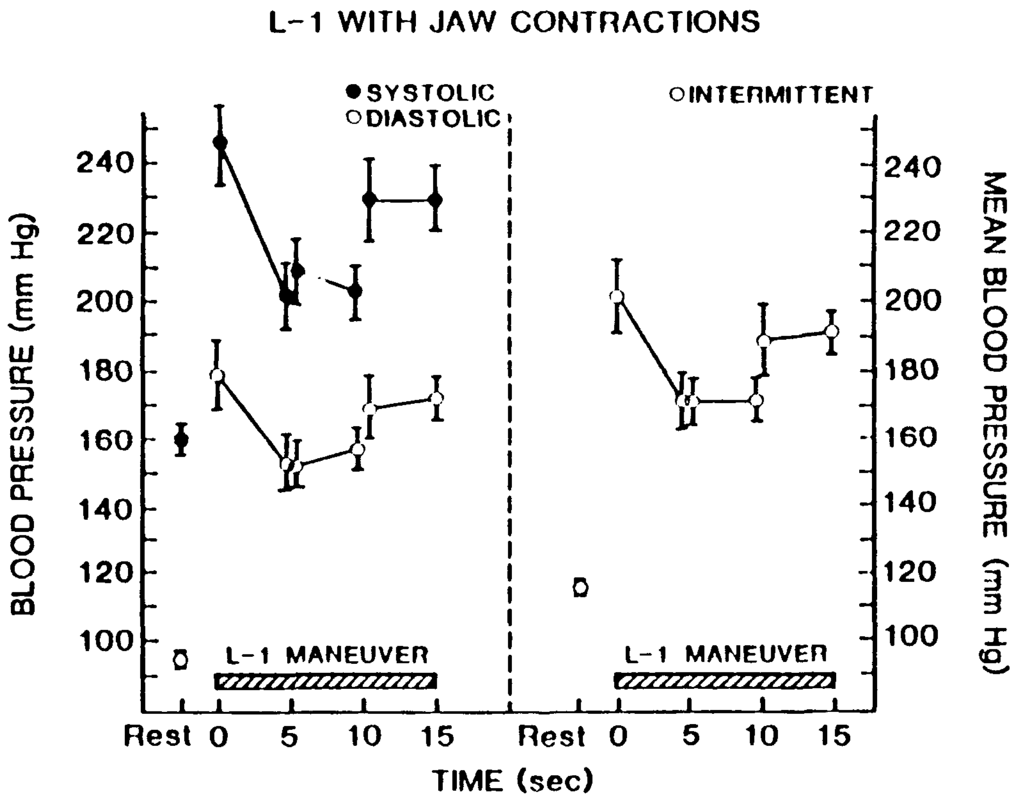

L-1 WITH JAW CONTRACTIONS
SYSTOLIC
DIASTOLIC
INTERMITTENT
BLOOD PRESSURE (mm Hg)
MEAN BLOOD PRESSURE (mm Hg)
240
220
200
180
160
140
120
100
L-1 MANEUVER
L-1 MANEUVER
Rest 0 5 10 15 Rest 0 5 10 15
TIME (sec)

Figure 7

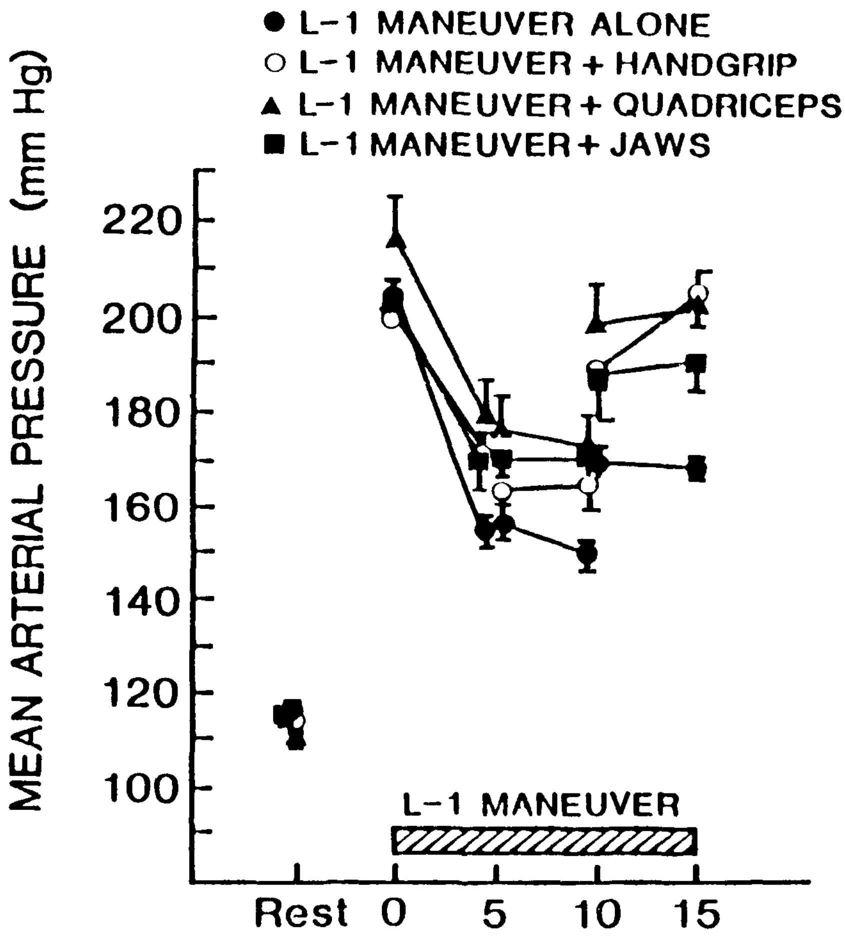

● L-1 MANEUVER ALONE
○ L-1 MANEUVER + HANDGRIP
▲ L-1 MANEUVER + QUADRICEPS
■ L-1 MANEUVER + JAWS
MEAN ARTERIAL PRESSURE (mm Hg)
220
200
180
160
140
120
100
L-1 MANEUVER
Rest
0
5
10
15

Figure 8

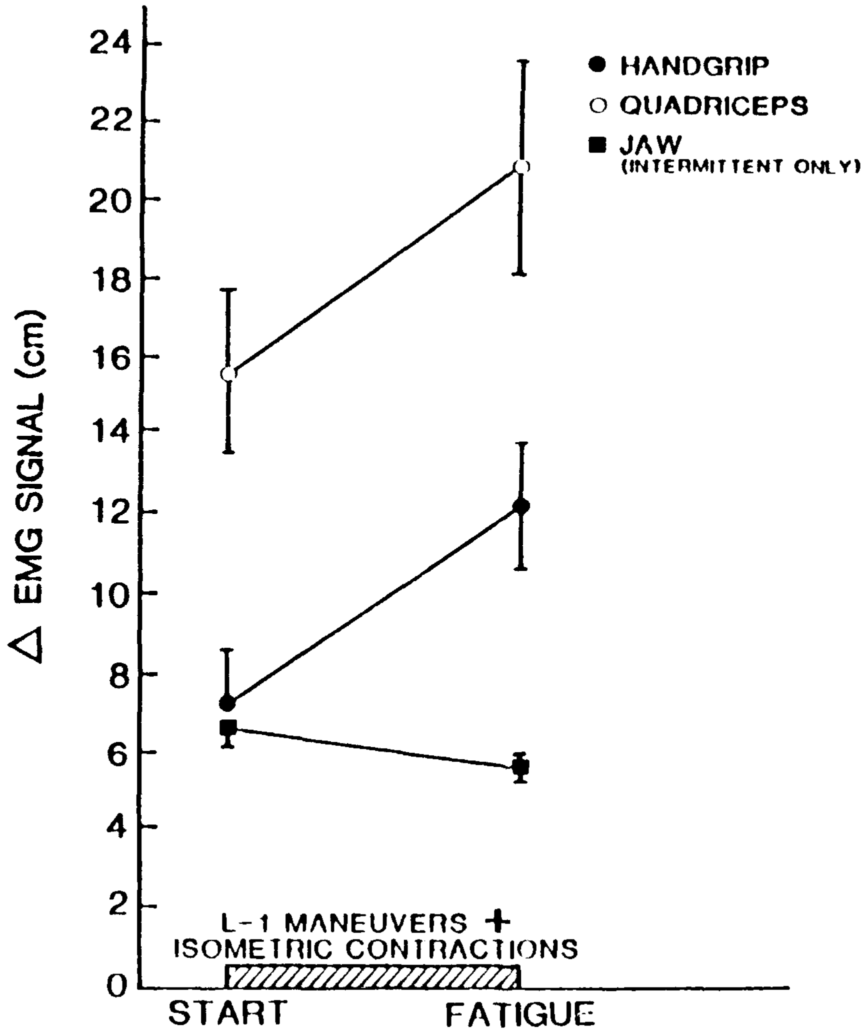


Figure 9

U.S.Government Printing Office 1990 748-002/20204